International Journal of Computer Networks and Distributed Computing
Vol. 4, Issue 2

Target Surveillance Lifetime Maximization in Wireless Sensor Networks

Ehsan Saradar Torshizi[1], Ahmad Alizadeh[2]

Computer Engineering Department, Urmia University, Urmia, Iran [1]

Computer Engineering Department, Islamic Azad University, Iran [2]

Abstract: In this paper, we study life time maximization problem for a target surveillance problem in wireless sensor networks. In fact, in the target surveillance problem, each target is required to be monitored by at least K different sensor nodes and each sensor node is able to monitor at most P different targets at each point of time. We introduce a new network model called CTCG (Connected Target Coverage Graph) and formulate the problem based on Linear Programming optimization. After solving the optimization problems a heuristic algorithm is taken advantage to obtain some cover trees which should be obeyed for a time period called Operation Time Interval (OTI) which is obtained as well. The goal is to maximize the coverage time of all targets by sink nodes which needs routing target's data toward the sinks as well as scheduling sensors activity.

Keywords: Target, Surveillance, Wireless Sensor Networks, Network Lifetime, Traffic modelling, Coverage

I. INTRODUCTION

Recent advances in micro-electro-mechanical systems, digital electronics, and wireless communications have led to the emergence of wireless sensor networks (WSNs). WSNs are comprised of a large number of sensors devices. Each sensor is capable of sensing, processing and transmitting. Besides, each sensor can monitor the targets that are located in its surveillance range [1].

In the target surveillance scenario, sensor nodes are used to monitor the targets and collect and transmit the monitored data to the sink node. The location of targets is assumed to be fixed and known for sensor nodes. Target surveillance is very useful in many applications such as monitoring the temperature of some machines in a factor, monitoring the chemical composition around some cargo containers which carry dangerous chemicals in long journey of shipment, etc.

Considering that sensors are typically energy-limited, the problem of optimizing the network lifetime while fulfilling target coverage requirements is an interesting and challenging issue. In fact, to maximize the network lifetime, there are three main approaches: 1) energy efficient routing (i.e. data packets are gathered and routed efficiently to the sink node[2]-[7]), 2) scheduling sensor node (i.e. the sensors are scheduled to take on or off modes in order to reduce energy consumption[8]-[12]) 3) integrated routing and sensor node scheduling (maximizing the network lifetime by jointly assuming the routing and scheduling problem [13]-[17]).

Early researches mainly focus on the sensor nodes to maximize the network lifetime, but a recent trend indicates a focus shift to the behavior of sinks [18]–[23], which can be exploited to further improve the lifetime of WSNs. The main reason that sink mobility can improve network lifetime lies in the fact that optimizing an objective in a high-dimension space always leads to a result no worse than what can be achieved in a subspace of reduced dimension.

In this paper, we investigate the problem of lifetime maximization for target surveillance in WSNs by jointly considering sink mobility, routing and scheduling. Given a set of targets and sensors in an area, the sensors are used to monitor the targets. Each sensor can monitor targets that are within its surveillance range, and a target can be located in the surveillance range of several sensors. Each sensor has a limited energy and is able to monitor at most P target at each point of time. Besides, each target should be monitor by K different sensor nodes. In fact, in some applications, it required to monitor each target with several sensors at each point of time.

The rest of this paper is organized as follows. Section II is the problem definition. Section III formulates the problem which introduced in section II. Simulation results are given in section IV. Finally, section V concludes the paper.

II. PROBLEM DEFINITION

We consider the following scenario. Targets with fixed known locations should be monitored by the sensors in field such that the sink node would be aware of the situation of each target continuously. Sensors are energy limited and

usually are not rechargeable. Running a sensor out of energy may cause the monitoring of some targets impossible. Besides, we assume that at the network startup all targets are covered by at least one sensor and there is a way from all sensors to the sink node. In addition, all of the sensors have the same communication and sensing range and they are aware of their location by using a localization mechanism. Furthermore, the location of the sink and targets are assumed to be known for sensor nodes.

Generally sensors can be categorized and scheduled by their assigned tasks. A sensor which performs sensing task and monitoring is called a source sensor. A sensor which does not perform sensing task and does relay task is called relay sensor. Note that a sensor can be both as source and relay node. If a sensor is a source sensor or/and relay sensor, it is an active sensor; otherwise it is in the sleep state. In this section we first formally define the three problems addressed throughout this paper.

A sensor which does sensing task and performs monitoring is called a source sensor and a sensor which doesn't perform sensing task and does relay task is called relay sensor. Note that a sensor can be both as source and relay node. If a sensor is a source sensor or/and relay sensor, It is an active sensor; otherwise it isn't an active sensor and it is in the sleep state.

We assume that all source sensors have the same data generation rate for a target. In the other words, all source sensors use the same sampling frequency, quantization, modulation and coding scheme for each target. Therefore, a fixed amount of bits, denoted by β which is called coverage rate, is generated by each source sensor for a target in a second.

Given N energy constrained sensors, M targets and a sink nodes, it is required to schedule the sensor such that:

1. Each target should be covered by at least K source sensors.
2. Each source sensor is connected directly to at most P target.
3. There should be a route from each source sensor to the sink node which passes through the relay nodes.

The many-to-one data flow pattern in WSNs which is also called as convergcast causes the sensors which are located near the sink nodes relay more data than the other ones. Relaying more data leads to more energy consumption. Therefore, sensors close to the sink nodes consume more energy than the other ones. In the same way, in CTC problem sensors which are connected to the sink node tends to run out of energy faster. Hence, specifying the optimal location for the sink node and the efficient routing for the sensors would improve the network lifetime notably.

Sink placement and routing have direct impact on each other. Indeed, for each sink location, there exists a particular efficient routing which maximize the network lifetime. On the other hand, sink location should be determined according to the routing algorithm. Although it is possible to decouple these two problems (see [give some citations]) but the best approach is to find the routing and sink position simultaneously. It should be stressed that, in reality the number of candidate points for sink placement is infinite. However, for sake of simplicity, the sink node can be located only in some restricted candidate points (i.e., the sensor locations).

Without loss of generality, we assume the target surveillance problem with N energy constrained sensors, M targets and a sink node. The sink node can move and change its location to maximize the network lifetime. Actually there are two approaches, unconstrained and constrained mobility, for exploiting sink mobility to improve network lifetime.

In unconstrained mobility scenarios, the sink node can be move to any point in the field. Since there is no limitation on the sink mobility, the number of possible locations for sink mobility is too many. By increasing the number of possible locations, the problem complexity increases too. But the optimal sink mobility pattern could be found by using this approach.

Conversely, the sink node can just move between a finite numbers of possible locations in constrained mobility scenarios. Given that only a handful of points are possible locations, the optimal answer cannot be always achievable. On the other hand, this approach has less complexity than the previous one. If the possible ones are good representatives for all locations, the answer would be close to the optimum answer.

In fact, sink mobility, no matter unconstrained or constrained mobility, can increase the network lifetime because mobility increases the dimension and the degree of freedom of the problem.

In this paper we focus on constrained mobility approach. The sink is constrained to where the sensor nodes are. Since the sensor nodes are scattered randomly in the field, sensors location can be a good handful of all possible locations in the field. Accordingly in target surveillance problem with mobile sink, routing and scheduling of the sensors and the sink sojourn time at each possible locations should be determined such that the network lifetime is maximized.

III. Proposed Formulation

In this section we first mention the formal formulation of the problems defined in previous section. The results of

proposed optimization approaches are used for obtaining some cover trees and their OTI (Operation Time Interval).

Let S= $\{s_1, s_2, s_3, ..., s_N\}$ ($|S|$=N) , L=$\{p_1, p_2, p_3, ..., p_M\}$ ($|L|$=M) and R denote the set of deployed sensor nodes , targets and the sink node, respectively.

Let S_s and S_r indicate the set of sensors which are in source and relay modes.

Let e_{ij}^t denotes the energy consumed to transmit a bit of data from node i to node j. Then it would be:

$$e_{ij}^t = e_t + b \times d_{ij}^\alpha \quad (1)$$

Where e_t and b are constants and d_{ij} is the Euclidean distance between node i and j. α is path loss parameter which takes value between [2,4]. Let e_r denotes the energy consumed for receiving a bit of data. Since the sender node controls its transmission power level, the receiver node consumes a constant amount of energy for receiving a bit of data. Let e_s denotes the energy consumed for sensing a target for a bit of data. Suppose that $\theta_s(\tau)$ denotes the number of targets which sensor s monitors them for τ seconds. If the coverage rate is β then the energy consumed in a source sensor for τ second is the sum of sensing and transmitting energy. So the energy consumed in a source sensor i which monitors $\theta_i(\tau)$ targets for τ second to and transmits the monitored information to node j would be:

$$E(i,\tau) = \beta.e_s.\theta_i(\tau) + \beta.e_{ij}^t.\theta_i(\tau) \quad i \in S_s and i \notin S_r (2)$$

A relay node receives data from its child nodes and transmits them to its parent. For a given relay node i,$\varphi_i(\tau)$ denotes the number of targets which node i relay their data for τ second. The energy consumed in relay sensor is the sum of its receiving and transmitting energy. So the energy consumed in a given relay sensor i which transmits its traffic to node j for τ second would be:

$$E(i,\tau) = \beta.e_r.\varphi_i(\tau) + \beta.e_{ij}^t.\varphi_i(\tau) \quad i \notin S_s and i \in S_r \ (3)$$

As mentioned before, a sensor can operate at both of source and relay mode. In this situation the energy consumed in τ second is equal to the summation of equation (2) and (3).A sensor which is neither in source nor in relay mode is in sleep mode and does not consume energy.

A. Proposed Formulation

Assume that the initial energy of each sensor is E_0.Let T denotes the network lifetime. For each target l, F_{ij}^l shows the total information flow from node i to node j which belongs to target P (i.e. monitored information of target l).

We also define t_k as the time span for the k th epoch. A new epoch begins when the sink node changes its location. We simplify the formulation by assuming that the sink is collocated with node k during the k th epoch. Therefore, t_k shows the sojourn time of the sink node at sensor k in second.

Hence, the linear formulation of the problem is as follows:

$$\text{Max} \quad Z = T \quad (4)$$

s.t

$$\sum_{\forall j \in S} F_{lj}^l = TK\beta \qquad \forall l \in L \quad (5)$$

$$\sum_{\forall j \in S \cup R} F_{ij}^l - \sum_{\forall m \in S \cup L} F_{mi}^l = t_i K\beta \qquad \forall i \in S, l \in L \quad (6)$$

$$\sum_{\forall m \in L} F_{mi}^m \leq TP\beta \qquad \forall i \in S \quad (7)$$

$$\sum_{\forall m \in S} F_{mi}^l = t_i K\beta \qquad \forall i \in S, l \in P \quad (8)$$

$$\sum_{\forall l \in L, j \in S \cup R} e_{ij}^t F_{ij}^l + \sum_{\forall l \in L, m \in S} e_r F_{mi}^l + \sum_{\forall l \in L} e_s F_{li}^l \leq E_0 - e_r t_i mK\beta \qquad \forall i \in S \quad (9)$$

$$\sum_{\forall i \in s} t_i = T \quad (10)$$

Based on the assumption, the objective function (4) aims to maximize network lifetime for target surveillance problem.

Constraints (5) are the flow balance constraints written for each target i. It guarantees that each target would be monitored by rate of βbits per second. Besides, traffic from each target will be ended at a sensor node. Indeed, we assume that sink node is not capable of sensing targets and is equipped only with receiving devise which enables it to receive data from sensor nodes.

Constraints (6) are the flow balance constraint written for each sensor i. It guarantees that total input flow to sensor is equal to total output flow in CTCG model. Obviously, input flow of each sensor starts from another sensor or a target and output flow of each sensor ends at a sink node or another sensor node.

Constraints (7) insure that each sensor node monitors at most P targets at each point of time.

We assumed that sink node is not capable of sensing a target and can just receive data from other sensors. Because of that, the total input flow to each sensor i from other sensors for each target should be equal to $t_i K\beta$. Constraints (7) should be written for each sensor node.

Constraints (8) insure that the sink node will receive its data from other sensors while the sink is co-located to sensor i. Since the sink node will stay at the location of sensor i fort_i secondsand receives data instead of the sensor i, the sensor node wont consume energy for receiving $t_i mK\beta$ bits (i.e. the sink node receive $mK\beta$ bits per second). Constraints (8) should be written for each sensor and target in the network.

Constraints (9) insure that the sum consumed energy for receiving, transmitting and sensing in each sensor is not greater that its initial energy. Constraint(9) should be written for each sensor node.

Constraint (10) insure that the total sojourn time of the sink node is equal to the network lifetime (i.e. sink mobility happens during the network lifetime).

By using the polynomial-time algorithms such as ellipsoid algorithm [24] we can solve the proposed linear programming formulation and determine the optimal result for each network.

The output of this formulation will be the network lifetime, sink sojourn time at each possible location and dataflow matrix which shows the routing in the optimal solution.

IV. Simulation Results

In this section, we evaluate the performance of proposed model by solving the proposed linear programming formulation. Furthermore, to demonstrate the superiority of our algorithm, we compare it with MLSTS (maximal lifetime sensor-target surveillance) introduced by [13] for different scenarios.

We simulate a stationary network which its sensors and targets are deployed randomly in a 100 m×100 m area. Data sensed from each target is generated by rate 10Kbps(β=10Kbps).

Each sensor covers a disk centered at itself with a fixed sensing range equal to the disk radius and for all sensors sensing range is equal to 20 m(R_s=20m)and they have the same maximum communication range which is equal to 40 m(R_c=40m). In static sink scenarios the sink node is located at the center of the field.

Each scenario plotted on the figure is the average of 20 networks which are generated randomly. LINGO [25] is used for solving the proposed linear programming formulations. Thereafter, OMNET++ [26] is used to simulate the solutions solve by LINGO (i.e. sink sojourn time at each possible location and dataflow matrix which shows the routing).

In Fig.3, for target surveillance problem, we study the impact of sensor density on the performance of our algorithm and compare it with target surveillance approach with static sink proposed in [13]. The number of sensors (N) varies between 40 and 100 while there are 20 randomly scattered targets (M=20) in each scenario. It target should be monitored by at least one sensor node (K=1). It can be seen that the lifetime achieved by our proposed approach is about 1.71 of proposed approach in [13].

In Fig.4, for full coverage, we evaluate our algorithm with different number of targets varying between20 to 70 and compare it with static sink method.

Apparently network lifetime decreases as the number of targets increase. More targets results in more data traffic in the network. The figure shows that the network lifetime achieved by mobile sink- is always higher than the one by static sink method.

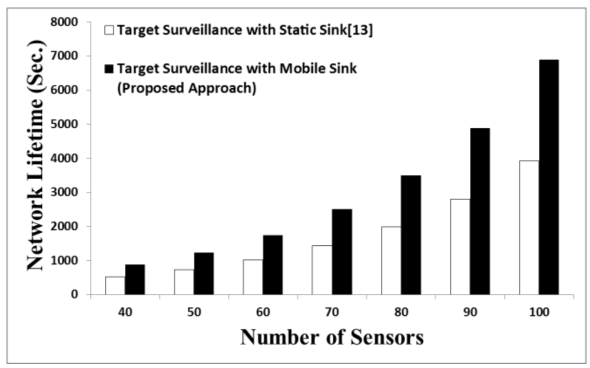

Fig. 3. Impact of sensor density on the target surveillance lifetime

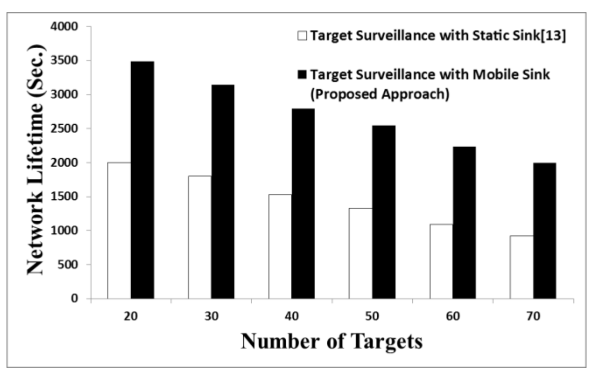

Fig. 4. Impact of target density on the target surveillance lifetime

In Fig.5, we study the impact of K on the performance of our algorithm. When K=1, each target should be monitored by at least on sensor at each point of time and when K=2 each target should be monitored by at least 2 different sensor nodes at each point of time.

Likewise, when K=3 each target should be monitored by at least 3 different sensor nodes at each point of time. We assume that at each target is located in the sensing range of at least *K* sensor at the network initialization.

When each target is required to be monitored by more sensors (i.e. K is increased), more sensor nodes are required to be in the source mode in order to monitor the specified targets.

Besides, the network traffic is increased when each target is required to be monitored by more sensor nodes at each point of time. However, Fig.5 indicates that using a mobile sink can improve the target surveillance lifetime.

In fact, when a static sink node is used, the sensors which are connected directly to the sink node, tends to run out of energy faster than the other sensor nodes in the network. By using a mobile sink, the heavy traffic load can be distributed on sensor nodes.

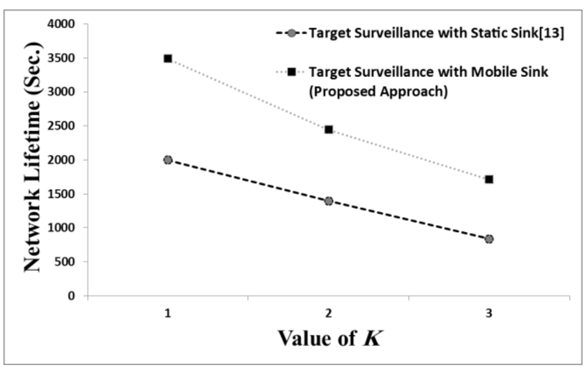

Fig. 5. Impact of *K* on the target surveillance lifetime

V. CONCLUSION

In this paper we study on the target surveillance problem in which fixed and static targets are required to be monitored by sensor nodes continuously. Each sensor has limited sensing range. Each one of the sensor nodes can monitor the targets which are located in its sensing range. Network lifetime increased not only by finding out the optimal routing and scheduling, but also finding out an appropriate location for the sink node.

We consider connectivity and coverage considering overlapped targets in our modeling and linear programming formulation and use a more realistic consumption model than the model used in [5] which didn't consider the number of observed targets in energy consumption model of each sensor.

At each point of time each target is required to be monitored by at least *K* different sensor nodes. Besides, each sensor node can monitor at most *P* target at each point of time.

Because of the limited energy at the sensor nodes, it is required to prolong the network lifetime. We proposed a simulation manner that is useful for reality implementation of the proposed algorithms and study the difference between theoretical results and the simulation results using our proposed simulation manner and try to figure out the reason for this difference.

REFERENCES

[1] C. S. Raghavendra, K. M. Sivalingam, , T. Znati, Wireless sensor networks. Springer, 2004.
[2] H. Frey, S. Ruehrup, and I. Stojmenovic, "Routing in Wireless Sensor Networks," Guide to Wireless Ad Hoc Networks, S. Misra, I. Woungag, and S. Misra, eds., ch. 4, pp. 81-111, Springer-Verlag, 2009.
[3] C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks," Proc. MObiCOM, 2000.
[4] A.M. Kermarrec, G. Tan, "Greedy Geographic Routing in Large-Scale Sensor Networks: A Minimum Network Decomposition Approach," Proc. 11th ACM Int'l Symp. Mobile Ad Hoc Networking and Computing (MobiHoc '10), pp. 161-170, 2010.
[5] L. Bao and J. Garcia-Luna-Aceves, "Topology management in ad hoc networks," in *Proc. ACM MobiHoc,* 129–140, 2003.
[6] R. Madan, S. Cui, S. Lal and A. Goldsmith, "Cross-layer design for lifetime maximization in interference-limited wireless sensor networks". Wireless Communications, IEEE Transactions on, 5(11), 3142-3152, 2006
[7] A. Misra and S. Banerjee. "MRPC: Maximizing network lifetime for reliable routing in wireless environments." Wireless Communications and Networking Conference. WCNC2002. 2002 IEEE. Vol. 2. IEEE, 2002.
[8] M. Cardei, M. Thai, Y. Li, and W. Wu, "Energy-Efficient Target Coverage in Wireless Sensor Networks," Proc. IEEE INFOCOM, 2005.
[9] M. Cardei, M. Thai, Y. Li, and W. Wu, "Energy-Efficient Target Coverage in Wireless Sensor Networks," Proc. IEEE INFOCOM, 2005.
[10] T. Yan, T. He, and J.A. Stankovic, "Differentiated Surveillance for
[11] Sensor Networks," Proc. First Int'l Conf. Embedded Networked Sensor Systems (SenSys '03), pp. 51-62, 2003.
[12] R. Subramanian and F. Fekri. "Sleep scheduling and lifetime maximization in sensor networks: fundamental limits and optimal solutions." In Proceedings of the 5th international conference on Information processing in sensor networks, pp. 218-225. ACM, 2006.
[13] H. Liu, X. Chu, Y.W. Leung, X. Jia, and P.J. Wan, P. J. "General maximal lifetime Sensor-Target surveillance problem and its

solution". Parallel and Distributed Systems, IEEE Transactions on, 22(10), 1757-1765,2011.

[14] F. Liu, C.Tsui, Y.J. Zhang, "Joint routing and sleep scheduling for lifetime maximization of wireless sensor networks". IEEE Trans. Wireless Commun. 9, 2258-2267, 2010.

[15] H. Liu, X. Jia, P.-J. Wan, C.-W. Yi, S. Makki, and N. Pissinou, "Maximizing Lifetime of Sensor Surveillance Systems," IEEE/ ACM Trans. Networking, vol. 15, no. 2, pp. 334-345, Apr. 2007.

[16] T. Yan, T. He, and J.A. Stankovic, "Differentiated Surveillance for Sensor Networks," Proc. First Int'l Conf. Embedded Networked Sensor Systems (SenSys '03), pp. 51-62, 2003.

[17] G. Lu, and K. Bhaskar. "Minimum latency joint scheduling and routing in wireless sensor networks." Ad Hoc Networks 5.6 (2007): 832-843,2007.

[18] J. Behnam, J. Cole Smith, and Ye Xia. "The Lifetime Maximization Problem in Wireless Sensor Networks with a Mobile Sink: MIP Formulations and Algorithms." IIE Transactions just-accepted (2013)..

[19] R. Shah, S. Roy, S. Jain, and W. Brunette, "Data MULEs: Mobeling a three-tier architecutre for sparse sensor networks," in Proc. IEEE SNPA, 2003, pp. 30–41.

[20] A. Chakrabarti, A. Sabharwal, and B. Aazhang, "Using predictable observer mobility for power efficient design of sensor networks," in Proc. IEEE IPSN, 2003, LNCS 2634, pp. 129–146

[21] E. Saradar Torshizi, S. Yousefi, and J. Bagherzadeh. "Life time maximization for connected target coverage in wireless sensor networks with sink mobility." Telecommunications (IST), 2012 Sixth International Symposium on. IEEE, 2012.

[22] J. Luo, and H. Jean-Pierre "Joint sink mobility and routing to maximize the lifetime of wireless sensor networks: the case of constrained mobility." IEEE/ACM Transactions on Networking (TON) 18.3 (2010): 871-884,2010.

[23] Y. Gu, J. Yusheng, L. Jie, R Fuji Ren and Z. Zhao. "EMS: Efficient Mobile Sink Scheduling in Wireless Sensor Networks." Ad Hoc Networks (2012).

[24] B. Robert, D. Goldfarb, and M.J. Todd. "The ellipsoid method: A survey." Operations Research (1981): 1039-1091.M. Shell. (2002) IEEEtran homepage on CTAN.

[25] OMNET++. [Online]. Available: www.omnetpp.org/

[26] LINGO. [Online]. Available: www.lindo.com/